The dry year 1910 is seemingly in a class by itself, as is also 1917. The onset of the first named was quite sudden as compared with the others shown in the figure. The year 1917 was one of maximum spottedness of the sun and that fact has been used by some in an effort to tie up the occurrence of droughts with the occurrence of many sun spots; the difficulty that must be faced by them is that the record shows that droughts occur almost simultaneously with both increasing and diminishing sun-spot numbers. (See Table 4.)

TABLE 4.—*Droughts in the United States and sun spots*

Year	Sun-spot curve		Smoothed sun-spot numbers			Nearest epoch of—	
	Rising	Falling	January	December	Year	Minimum	Maximum
1854		F	28.2	15.6	21.0	1856.0	
1856	R		3.3	9.3	5.2	1856.0	
1857	R		10.5	36.0	23.0	1856.0	
1860		F	97.2	90.6	94.8		1860.1
1863		F	51.9	43.2	45.4		1860.1
1864	R [1]	F	44.8	41.3	45.2	1867.2	
1870	R		110.0	135.4	131.8		1870.6
1881	R		47.0	62.4	54.4	1878.9	
1893	R		78.0	86.7	83.7		1894.1
1894		F	87.9	71.3	79.1		1894.1
1895		F	67.7	52.5	61.5		1894.1
1901		F	4.8	2.8	3.4	1901.7	
1910		F [2]	31.5	12.8	21.0	1913.6	
1916	R		57.8	68.7	59.1		1917.6
1917	R		73.4	98.3	96.2		1917.6
1924	R		0.5	16.5	16.7	1923.6	
1930		F	63.7	28.0			1928.0

[1] Rising followed by falling.
[2] The driest year in the United States in forty-odd years.

The 1924–25 drought had its beginning in 1921 and was distinguishable as late as 1926, although in that year a number of States had more than the average precipitation. It happens, not infrequently, that one and the same year may yield abundant rain in one part of the country and withhold it in another, as illustrated by 1927, the year of the great Mississippi flood. In that year Florida, Georgia, and South Carolina suffered more or less from drought.

YEARS OF GREATEST PRECIPITATION

The chronological record of years with greater than the normal precipitation as summarized from the data of Table 2 is presented in Figure 2. In that figure I have indicated the probable grouping of years of greater than the normal precipitation by inclosing them in continuous lines. These years occur also in groups as in the case of years of deficient rainfall. The groups are centered about 1890, 1898, 1902, 1905, 1909, 1912, 1915, 1919, 1923, and finally in 1927, 1928, and 1929.

The average interval between these dates is roughly four years.

If the figures of the extreme right-hand column of Tables 3 and 4 be smoothed by the formula $\left(\frac{a+2b+c}{4}\right)$ and the smoothed values be plotted against time as abscissa the resulting curve indicates a period of approximately four years between epochs of maximum and minimum. I attach no great importance to these curves, since the smoothing process distorts or rather displaces the epochs of maximum and minimum and reduces the amplitude of the oscillations.

Figure 2 is complementary to Figure 1, since it presents the grouping of the opposite extreme in the annual precipitation. Viewing the two figures one must be struck with the apparent absence of chance in the annual distribution of precipitation; rather these two figures favor the idea that the years of little and much rainfall succeed each other in a wave like sort of motion which advance from west to east and perhaps in due course encircle the globe. It is also possible to identify in them the well-known Brückner years of dry and wet weather said to repeat themselves in a period of 35 years.

Another outstanding feature to which attention is invited is that years of drought do not come suddenly and unheralded but almost uniformly preceded by one or two years of diminished precipitation in various parts of the United States; likewise peak dry years are sometimes followed immediately by one or two years of fairly good rains apparently intercalated in a series of dry years as in 1902–03 and again in 1915–16.

Conclusions.—The facts hereinbefore presented lead to the belief that in the great majority of cases the total annual precipitation may be used as a criterion on drought; it must, however, be used intelligently, bearing in mind that the area under consideration with up to 70 per cent of its annual normal rainfall may have been very dry in spots but as whole the deficit may not have been equally pronounced.

In the Pacific coast and Plateau States any one year with but 60 per cent of its annual precipitation may be classed as a dry year. In the Great Plains States, excepting South Dakota, 65 per cent, while not as low as has been reached in past droughts may be accepted as a measure of severe drought. In the Gulf States the range is from 70 to 75 per cent and in the Northeastern States the lower limit is from 75 to 85 per cent.

SOLAR RADIATION INTENSITIES WITHIN THE ARCTIC CIRCLE

By HERBERT H. KIMBALL

[Weather Bureau, Washington, D. C., April 15, 1931]

In summaries of solar radiation measurements prepared by the author,[1] the following stations within, or practically on the Arctic Circle have been listed:

Abisko, Sweden, latitude 68° 21′ N., longitude 18° 49′ E., altitude 390 meters.

Jokkmokk, Sweden, latitude 66° 36′ N., longitude 19° 51′ E., altitude 255 meters.

Mount Evans, Greenland, latitude 66° 51′ N., longitude 50° 50′ W., altitude 394 meters.

Rovaniemi, Finland, latitude 66° 29′ N., longitude 25° 44′ E., altitude 200 meters.

Treurenberg, Spitzbergen, latitude 79° 55′ N., longitude 16° 52′ E., altitude 9 meters.

At these stations solar radiation intensity at normal incidence was measured. Now we may add to the above list Green Harbor, Spitzbergen, latitude 78° 00′ N., longitude 14° 05′ E., with continuous measurements of the total solar radiation (direct + diffuse) received on a horizontal surface.

SOLAR RADIATION MEASUREMENTS AT GREEN HARBOR, SPITZBERGEN

At the second general assembly of the International Geodetic and Geophysical Union at Madrid, in 1924, the

[1] Measurements of solar radiation itensity and determinations of its depletion by the atmosphere. MONTHLY WEATHER REVIEW, 55: 155, April, 1927; 58: 43, February, 1930.

Meteorological Section set aside the sum of £400 for the purchase of self-recording pyrheliometers or pyrgeometers for use in northern Canada or Spitzbergen, New Zealand or Samoa, Brazil or Belgian Congo, and the South Orkneys.

For Spitzbergen a Gorczyński recording solarimeter was obtained, and was installed by Dr. H. U. Sverdrup at Green Harbor at the beginning of September, 1927. The instrument is designed to give a continuous record of the total solar radiation received on a horizontal surface directly from the sun and diffusely from the sky. In transmitting a summary of the measurements Doctor Sverdrup makes the following statement:

> These records have been obtained by means of a Gorczyński recording instrument which was delivered by Kipp & Zonen, and installed by myself at the Norwegian radio station. The records have been reduced at the Geophysical Institute in Bergen, using the constant for the instrument which was obtained from the makers. This constant, according to comparisons with records from Finland, can be regarded as fairly accurate. No absolute observations were undertaken at Green Harbor, since there was no trained observer at the station.

As tabulated at Bergen the average intensity of solar radiation is given for each hour of each day, central on the full hour. The maximum intensity for each day is also given. From the latitude of Green Harbor, and neglecting atmospheric refraction, we would expect the sun to appear above the southern horizon on February 17 and to disappear below it on October 25. Actually, the first sunshine in spring was recorded on February 26 and the last in fall on October 18. Also, we would expect solar radiation throughout the 24 hours from April 21 to August 21. Actually, the first day in spring with solar radiation during every hour is April 29, although recorded at midnight after the 25th. The sun was continuously above the horizon on August 9 when the record ended.

TABLE 1.—*Total solar radiation (direct+difuse) measured at Green Harbor, Svalbard. Latitude 78° 00′ N., longitude 14° 05′ E.*

[Gram-calories per square centimeter of horizontal surface]

Week beginning	Average daily	Maximum daily	Maximum hourly	Maximum per minute
1927	*cal.*	*cal.*	*cal.*	*cal.*
Sept. 4 [1]	131	184	26	0. 55
Sept. 10	107	135	20	0. 38
Sept. 17	56	72	13	0. 33
Sept. 24	45	68	14	0. 19
Oct. 1	15	17	4	0. 14
Oct. 8	12	19	5	0. 12
Oct. 15 [2]	5	7	3	0. 05
1928				
Feb. 26	7	11	3	0. 06
Mar. 4	18	27	5	0. 12
Mar. 11	43	50	8	0. 21
Mar. 18	75	86	13	0. 24
Mar. 25	101	131	19	0. 38
Apr. 1	133	185	23	0. 41
Apr. 8	180	216	26	0. 58
Apr. 15	233	301	31	0. 69
Apr. 22	320	373	35	0. 83
Apr. 29	303	355	37	0. 83
May 6	428	447	43	0. 92
May 13	450	502	44	0. 91
May 20	445	517	50	1. 10
May 27	505	521	46	1. 09
June 3	447	592	47	0. 91
June 10	562	[5] 652	53	1. 43
June 17	615	644	49	0. 85
June 24 [3]	562	643	49	0. 81
July 2	480	622	51	1. 03
July 9	296	506	46	1. 07
July 16	358	536	44	0. 90
July 23	340	443	40	0. 73
July 30	340	416	38	0. 76
Aug. 6 [4]	273	365	33	0. 66

[1] 6 days only. [2] 4 days only. [3] 8 days. [4] 4 days only.
[5] The sum of maximum hourly amounts for the respective hours=712 gr. cals.

In Table 1 the data as originally tabulated have been summarized by weeks, giving for each week the average daily amount of radiation expressed in gram-calories per square centimeter of horizontal surface, and also the maximum per day, per hour, and per minute. There are frequent gaps in the record, especially at about 8 a. m. The average daily amounts are based on such data as has been furnished, with interpolations where practicable.

In June the maximum total is less than that computed by me for June 21 with cloudless sky at Latitude 60° and 90° north, and the average daily total is greater.[2] From this I conclude that at Green Harbor in June one does not often find 24 hours with skies continuously free from clouds and fog, and that, on the other hand, the average cloudiness is not as great as has been observed at other Arctic stations, or at least that this was the case in 1928.

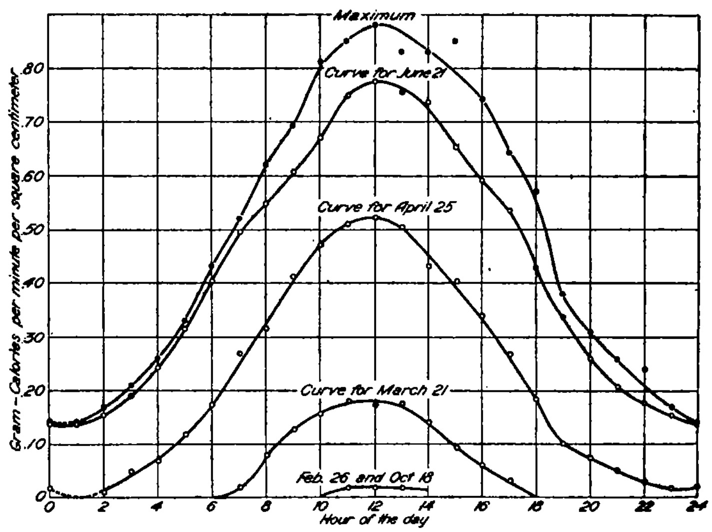

FIG. 1.—Diurnal march of solar radiation at Green Harbor, Spitzbergen, for different epochs of the year. (The time scale is on apparent, or true solar time.)

Without having seen the original record sheets, there appears to be some question about the accuracy of the maximum radiation per minute (1.43 gram-calories) recorded on June 10. At noon on this day the solar altitude was only slightly in excess of 35°. The intensity of direct solar radiation could hardly have exceeded 1.5 gram-calories per minute per square centimeter, and its vertical component would be $1.50 \times 0.574 = 0.86$, leaving 0.57 gram-calories per minute per square centimeter for sky radiation. This amount could have been received only under the most favorable conditions for reflection of light from clouds between the sun and the zenith. A well-authenticated increase in the intensity of solar radiation of 20 per cent due to reflection from clouds occurred at Mount Weather, Va., on July 28, 1912.[3] The percentage increase at Green Harbor appears to have been considerably greater, or from 25 to 30 per cent. Possibly reflection from the snow and ice covered ground surface to the under side of the cloud and then back to the earth would account for the excessively high radiation intensity in question.

In Figure 1 the diurnal march of radiation is represented by the hourly intensities for the first day in spring and the last day in autumn on which records were ob-

[2] Kimball, Herbert H. Amount of solar radiation that reaches the surface of the earth on the land and on the sea, and methods by which it is measured. MONTHLY WEATHER REVIEW, vol. 56:393, 1928.

[3] Kimball, Herbert H., and Miller, Eric. The Influence of Clouds on the Distribution of Solar Radiation. Bull. Mt. Weather Obs., 5:166, 1912.

tained, by the hourly averages for March 18–24, the week of the vernal equinox, for April 22–28, the first week on which radiation was recorded at midnight, for June 17–23, the week of the summer solstice, and finally a curve representing the maximum average hourly intensities recorded in each of the 24 hours. The sum of these last-named hourly averages multiplied by 60 gives the maximum daily radiation with clear skies for the year.

It is to be noted that the average daily amount for the three weeks centering on the summer solstice is greater than the average of the daily normals for this period for any stations in the United States except Twin Falls, Idaho, and Fresno, Calif., as given in Table 4, MONTHLY WEATHER REVIEW for February, 1930, volume 58, page 45.

What must be the effect upon plant and animal life of this stimulus of continuous solar radiant energy during four months of the year? In lower latitudes it has been found that generally plants as well as animals require the night hours of rest for their best development.

SOLAR RADIATION MEASUREMENTS MADE AT MOUNT EVANS, GREENLAND

These measurements were made by C. R. Kallquist and Prof. J. E. Church, jr., members of the University of Michigan Greenland Expedition, between August 13, 1927, and April 17, 1928, which covers a part of the period during which measurements of solar radiation were made at Green Harbor, Spitzbergen. The instrument employed was of the Moll type of thermoelectric pyrheliometer, mounted in a diaphragmed tube, with attachments that enabled the observer to keep the instrument accurately pointed on the sun. The current generated by the heating effect of solar radiation on the free junction of the pile was determined by an eye reading on a Weston millivoltmeter. The pyrheliometer was carefully standardized at the United States Weather Bureau before the departure of the expedition, to determine the e. m. f. developed in the pile by solar radiation of known intensity. It was hoped to recalibrate the instrument after its return from Greenland. Unfortunately, however, while the pyrheliometer was received back in excellent condition the millivoltmeter was ruined by the upsetting of a boat in which it was being transported. A satisfactory recalibration of the complete apparatus was therefore impossible.

A brief summary of these measurements was given by me in a paper in the Review for February, 1930.[4] They are here summarized in more detail.

TABLE 2.—*Pyrheliometric readings made by Prof. J. E. Church, jr., during trip to and on inland ice. Direction of travel, east from latitude 66° 50′ N., longitude 51° W., total distance, 30 miles*

[Gram-calories per minute per square centimeter of normal surface]

Date	Air mass									
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
1927	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.
Aug. 13, a. m.	1.43	1.32	1.20							
Aug. 13, p. m.		1.33	1.23	1.15	1.07	1.00	0.94	0.88	0.84	0.80
Aug. 14, a. m.	1.44	1.35	1.26							
Aug. 14, p. m.		1.33	1.24	1.16	1.08	1.02	0.96	0.91	0.86	0.81
Aug. 15, a. m.	1.45	1.33	1.23	1.16	1.09	1.03				
Aug. 15, p. m.		1.33	1.23	1.12	1.08	0.95	0.89	0.86	0.84	0.82
Aug. 16, a. m.	1.30	1.22	1.16	1.09	1.02	0.96	0.91			
Aug. 16, p. m.			1.16	1.10						
Aug. 17, a. m.	1.40	1.32	1.25	1.18	1.12	1.07	1.04	1.01	0.98	0.97
Aug. 17, p. m.		1.34	1.21	1.10						
Aug. 20, a. m.	1.38	1.29	1.20	1.14	1.08	1.04	1.00	0.96		
Means	1.40	1.32	1.22	1.13	1.07	1.01	0.96	0.92	0.88	0.85

[4] Kimball, Herbert H. Measurements of solar radiation intensity and determinations of its depletion by the atmosphere. Monthly Weather Review. 58:43.

Table 2 summarizes measurements made by Professor Church, between August 13 and 16, inclusive, on the journey from the shore to the inland ice, at altitude of from 250 to 450 feet above sea level; on August 17 at the edge of the ice where the altitude was about 950 feet and on August 20 on the inland ice, at an altitude of between 1,600 and 1,800 feet. The distance covered was about 30 miles, and the direction traveled was approximately east, so that there was little change in latitude. The change of correction necessary to reduce forty-fifth meridian time to apparent time was taken into account in computing solar altitudes corresponding to the time at which the measurements were made. Solar altitudes at noon varied from 37° 45′ on August 13 to 35° 32′ on August 20, corresponding to air masses 1.63 and 1.72, respectively. The intensities for air mass 1.5 and 1.0 were therefore obtained by extrapolation.

Table 3 summarizes measurements made by C. R. Kallquist at Mount Evans, Greenland, on the inland ice, at an altitude of 1,228 feet (374 meters). Slight extrapolations have in a few cases been necessary to obtain the intensities tabulated. In general, the readings indicate a very pure and dry atmosphere, as is shown by the values for the atmospheric transmission given in Table 4.

TABLE 3.—*Pyrheliometric readings made by C. R. Kallquist at Mount Evans, Greenland. Latitude 66° 51′ N., longitude 50° 50′ W., altitude 1,228 feet*

[Gram-calories per minute per square centimeter of normal surface]

Date	Solar altitude												Vapor pressure
	30.0°	23.5°	19.3°	16.4°	14.3°	11.3°	9.3°	7.8°	6.8°	3.1°	1.8°	0.7°	
	Air mass												
	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	15.0	21.0	30.0	
1927	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
Sept. 6, p. m.	1.32	1.26	1.20										4.75
Sept. 7, p. m.	1.31	1.26											4.37
Sept. 17, p. m.		1.34	1.25	1.19	1.15	1.08	1.01			0.42			
Sept. 18, p. m.		1.30	1.24	1.19	1.14	1.07	1.02				0.62		
Sept. 20, p. m.		1.40	1.23	1.22						0.65			2.74
Sept. 22, p. m.				1.18	1.14	1.08							
Sept. 24, p. m.		1.31	1.25	1.20									2.62
Sept. 25, p. m.			1.30	1.22	1.18	1.11							2.74
Means	1.32	1.31	1.25	1.20	1.15	1.08	1.02			0.54	0.62		3.44
Oct. 12, a. m.				1.28	1.21	1.10	1.03						2.16
Oct. 12, p. m.				1.22	1.16	1.06							
Means				1.25	1.18	1.08	1.03						
1928													
Feb. 18, p. m.						1.25	1.14	1.10	1.09	0.76		0.27	0.38
Mar. 20, a. m.		1.47	1.39	1.34	1.30								0.51
Mar. 20, p. m.		1.56	1.39		1.32	1.18	1.07						
Means		1.52	1.39	1.34	1.31	1.18	1.07						
Apr. 3, a. m.	1.47	1.38	1.30	1.22									1.52
Apr. 3, p. m.	1.50	1.38	1.29	1.24	1.19								
Apr. 4, a. m.	1.44	1.40	1.33	1.28									0.58
Apr. 4, p. m.		1.35	1.25	1.15	1.06								
Apr. 17, a. m.	1.38												2.74
Apr. 17, p. m.	1.34	1.28	1.22	1.18	1.12	1.03	0.94	0.86					
Means	1.43	1.36	1.28	1.21	1.12	1.03	0.94	0.86					1.61

TABLE 4.—*Atmospheric transmission for solar radiation*

Date	Solar altitude	Air mass		Intensity	Vapor pressure	Precipitable water	Atmospheric transmission		Difference
		m	$m\frac{P}{760}$	I			$I/I_x{}^3$	Computed	
1928	°			Gr. cal. min. cm.²	Millimeters	Centimeters			
Mar. 20	14.3	4.0	3.80	1.31	0.51	0.11	0.675	0.705	0.030
Do	19.3	3.0	2.85	1.39	0.51	0.11	0.716	0.752	0.036
Apr. 17	30.0	2.0	1.90	1.36	2.74	0.605	0.707	0.746	0.039
Sept. 6–7	30.0	2.0	1.90	1.31	4.57	1.00	0.693	0.721	0.028